Design of Blowout Preventer Lifting Frame

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Abstract

A Blowout Preventer is a large, specialized valve usually installed redundantly in stacks used to seal, control and monitor oil and gas wells. Blowout preventers developed to cope with extreme erratic pressures and uncontrolled flow emanating from a well reservoir during drilling. These are widely used at land, offshore rigs and subsea. Lifting BOP stack (blowout preventer) is a difficult task due to its huge size and complex shape without any interface like lifting frame. It is also not possible to accommodate lifting lugs on BOP stack because of its tough geometry. Hence, the importance of lifting frame is determined and designed for Hydrill GK 13 5/8"-5000 Annular BOP. The safe working load of the BOP stack is 34.6 MT (76.27 kips). Size and shape of the lifting frame are determined against the shape and particulars of the annular blowout preventer. Lifting frame is designed as a two point lifting system. Design of lifting frame includes the design of lifting pad eyes, annular locking padeyes and bolts strength calculations. Standard contact analysis is used to simulate the connecting parts of the lifting frame. Finite element analysis is carried out by using ANSYS 12.0.1.

Keywords

Blowout Preventer; Lifting Frame; BOP; Lifting Ring; Annular Guide; Annular Padeye

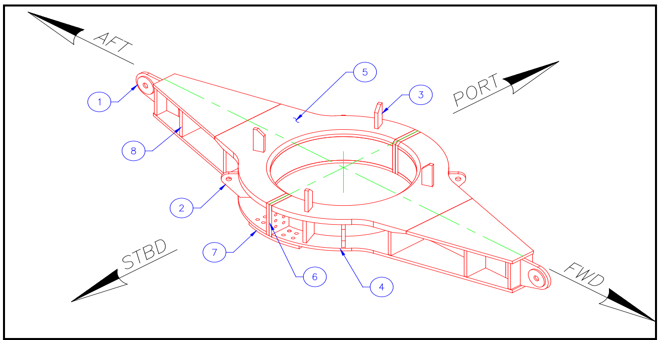
Introduction

A BOP stack is composed of several individual blowout preventers serving various functions that are assembled or stacked together, with at least one annular BOP on top of the several ram BOPs. These various BOPs can seal around the drill pipe, casing, close over the wellbore and cut through the drill pipe with steel shearing blades. BOP stacks are more in weight and size, due to its larger size lifting frame designed to lift the BOP stack. Lifting frame is a work frame used for lifting or lowering the equipments. There are several reasons for using these lifting frames in shipyards. Lifting frame experiences more dynamic movements while lifting the BOP stack due to its weight and size, which may result in hitting the surrounding machinery/equipment. Sometimes it is also not possible to accommodate the lifting lugs on its surface because of its complex geometry. So for movement of heavy equipments in shipyards, lifting frames are greater in requirement. These frames are used to move the equipment or machinery from fabrication shed to the vessel (offshore or marine vessel) and also useful while moving one place to the other place on vessel as per the requirement. There are several advantages in using the lifting frames; provision of lifting frame can handle the materials efficiently and with minimum physical effort must be one of the most important considerations in industry today. On one hand, there is growing pressure on management from workers, their trade unions and safety representatives, to provide lifting equipment to ease their daily tasks; on the other hand, an increasing awareness of the greater efficiency and reduced costs can be obtained by employing modern mechanical handling equipment of all capacities. The objective of the present study is the design of lifting frame for design working load of the BOP stack. This study also gives the design calculations of lifting frame padeye, annular locking padeye and bolts strength calculations.

Hydrill GK 13 5/8" - 5000 Annular BOP Lifting Frame Design

In the present paper lifting frame is designed for Hydrill GK 13 5/8" - 5000 Annular BOP. The Annular BOP sits on top of three ram BOPs. While lifting, lifting frame will hold the BOP stack around the annular BOP. Lifting frame is designed into two parts; and both the parts are almost similar except the annular guide locations. Main components of the lifting frame are lifting frame padeyes, annular guides, annular locking padeyes, bottom plate, top plate, vertical face plates, bottom connecting plates and ribs. Top and bottom plate of the lifting frame parts are connected by using vertical plates. All the parts of the lifting frame are shown in FIG. 1. Lifting frame is mainly designed for moving BOP stack from one location to other as per the requirement on offshore drilling rig. Crane used for lifting BOP stack is gantry crane, having SWL capacity of 100 MT. Gantry crane will lift the BOP stack by using two hoists which are

fitted in a hoist trolley and can move horizontally on pair of rails fitted under a beam. The distance between these two hoists is 147", so the lifting frame is designed as two point lifting system. Offshore cranes can also use this lifting frame for moving BOP stack from its place in shed to the vessel. Inner ring diameter of the lifting frame is determined based on 'N' (3'-2") and 'O' (3'-8 3/4") dimensions of the Hydrill GK 13 5/8" - 5000 Annular BOP, shown in Fig. 2. The outer ring diameter, other parts size and shape of the lifting frame are determined as per the finite element analysis results and design calculations. Based on the iterative process of FE analysis, it is determined to add bottom connecting plate at connecting location of the lifting frame parts, resulting in drastic reduction of von-Mises stresses in the lifting frame.



1. Lifting frame padeye
2. Annular locking padeye
3. Annular guide
4. Bottom plate
5. Top plate
6. Vertical face plate
7. Bottom connecting plate
8. Ribs

FIG. 1 MAIN PARTS OF THE BOP LIFTING FRAME

Annular locking padeyes and annular guides play vital role in lifting the BOP stack. Lifting frame annular locking padeyes will be connected with the annular lugs using shackles and chains. Both lifting frame annular locking padeyes and annular guides are helpful for sea fastening the BOP Hydril annular during the lifting operation. 25 MT shackles are used for lifting padeyes and 9.5 MT shackles are used for annular locking pad eyes; while these shackles are standard shackles available in the market. Lifting frame padeyes and annular locking padeyes are not standard padeyes, but fabricated padeyes. All padeye holes will be drilled after all welding is completed. Pin hole and padeye edges are smooth and free from any imperfections. Main particulars of the lifting frame are:

1. Length of the lifting frame (lifting padeyes center to center distance), 12'-3"
2. Maximum width of the lifting frame, 4'-8 6/8"
3. Depth of the lifting frame, 1'-2"
4. Inner ring diameter of the lifting frame, 3'-3"

Procedure for lifting frame parts assembly: When BOP annular on its place both the lifting frame parts are assembled from either side of the BOP annular and then both the parts are connected by using bolt and nuts through vertical face plates. In later stage bottom connecting plate will be connected to the lifting frame by using bolt and nut connections. Shackles are attached to the corresponding padeyes. Lifting frame parts are shown in Fig. 3.

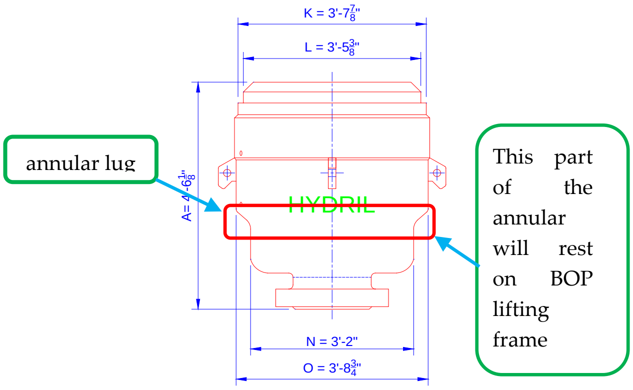


FIG. 2 PARTICULARS OF HYDRILL GK 13 5/8" - 5000 ANNULAR BOP

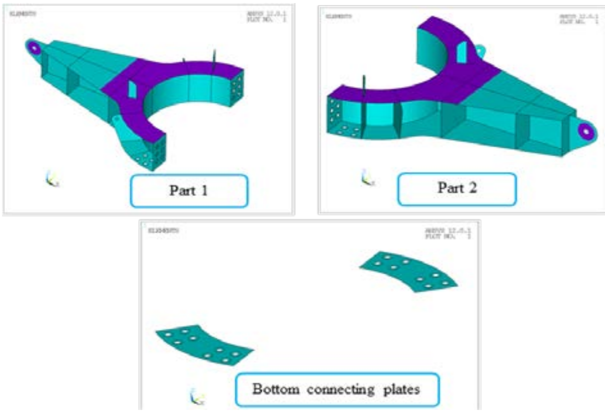


FIG. 3 BLOWOUT PREVENTER LIFTING FRAME PARTS

Material Properties of the Lifting Frame and Hex. 1 1 /8" $\phi \times 4$" LG Bolts

Material properties of the lifting frame and bolts are given in Table 1.

TABLE 1 MATERIAL PROPERTIES OF THE LIFTING FRAME AND HEX. BOLT 1 1 /8" Φ × 4" LG

	Lifting frame	**Hex. Bolt 1 1 /8" φ × 4" LG**
Material grade	ASTM A36	ASTM A325
Density of steel,	490 lbs / ft³	490 lbs / ft³
Yield strength, f_y	34 ksi (234 MPa)	92 ksi (634.3 MPa)
Ultimate	58 ksi (400 MPa)	120 ksi (827.3 MPa)
Young's	30457.9 ksi (210GPa)	30457.9 ksi
Poisons ratio, ν	0.3	0.3

Finite Element Modelling of the BOP Lifting Frame

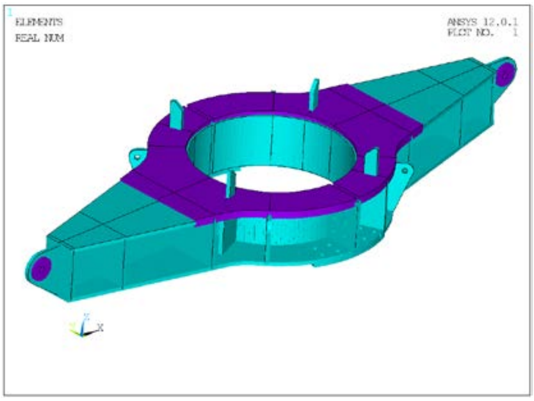


FIG. 4 SURFACE MODEL OF THE BOP LIFTING FRAME

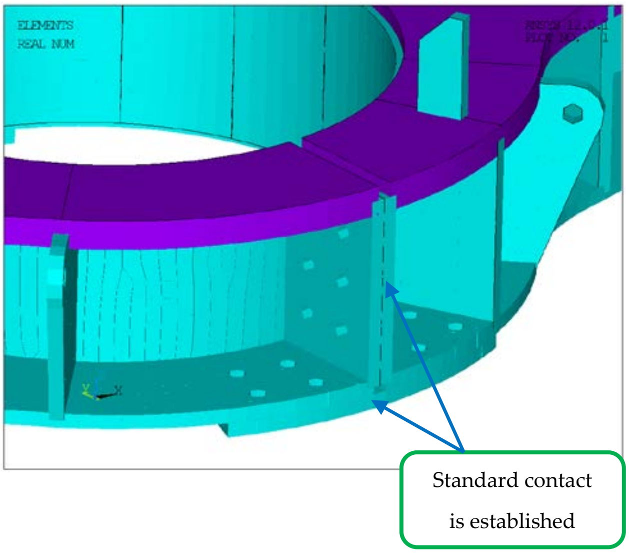


FIG. 5 SURFACE MODEL OF THE BOP LIFTING FRAME (ZOOMED VIEW) (SIZE AND SHAPE DISPLAY OF ELEMENT IS ON, ANSYS 12.0.1)

The finite element model of the BOP lifting frame is modelled in HyperMesh 10.1. Mid plane surface of the lifting frame structure is modelled using 4-noded quadrilateral shell elements (Element type: Shell 63). The finite element model plots of the lifting frame are shown in Fig. 4 to Fig. 8. Surface to Surface contact option (element type: Conta 174, Targe 170) is used to simulate the contact regions between vertical face plates and bottom plate of the lifting frame & bottom connecting plate. Contact regions are clearly shown in Fig. 5. Contact regions are connected together by means of bolted connections, reference to Fig. 9 and Fig. 10. Bolts are modelled as beam elements (Element type: Beam 44) and connected with CERIG to the boundary nodes of bolt hole. Holes are created at bolt locations, and diameter of the hole is equal to bolt diameter. Bolts are simulated as beam elements. Two sets of nodes are considered around the bolt region to simulate washer area, reference to Fig. 7. Grid independent study has been conducted to determine the mesh size of the element. The size of the element is about 2". Summary of finite element model is: Total number of elements = 8239, Total number of nodes = 7529.

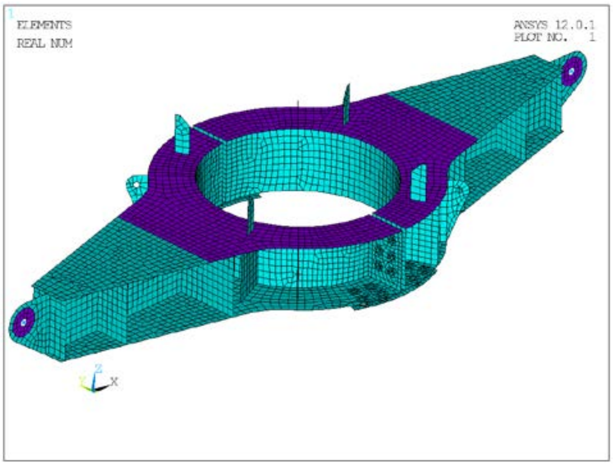


FIG. 6 FINITE ELEMENT MODEL OF THE BOP LIFTING FRAME

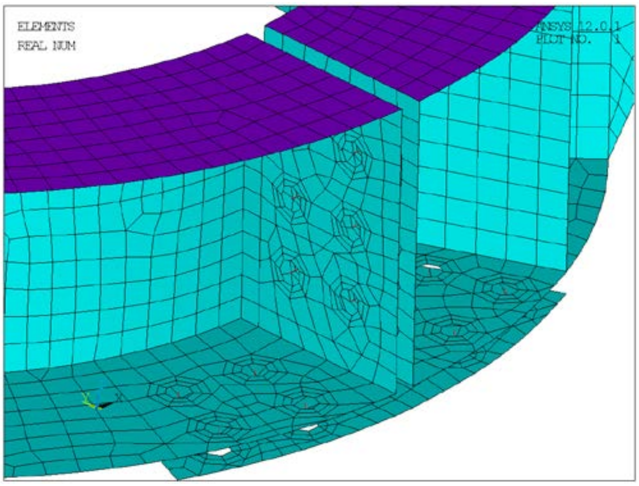


FIG. 7 FINITE ELEMENT MODEL OF THE BOP LIFTING FRAME

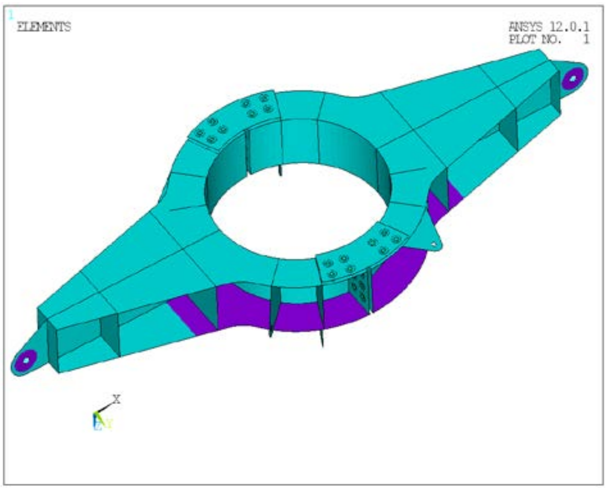


FIG. 8 SURFACE MODEL OF THE BOP LIFTING FRAME (VIEW FROM BOTTOM)

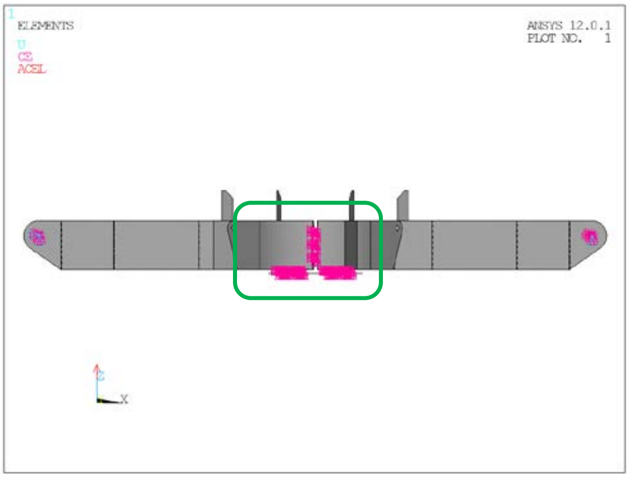


FIG. 9 PROFILE VIEW OF THE BOP LIFTING FRAME

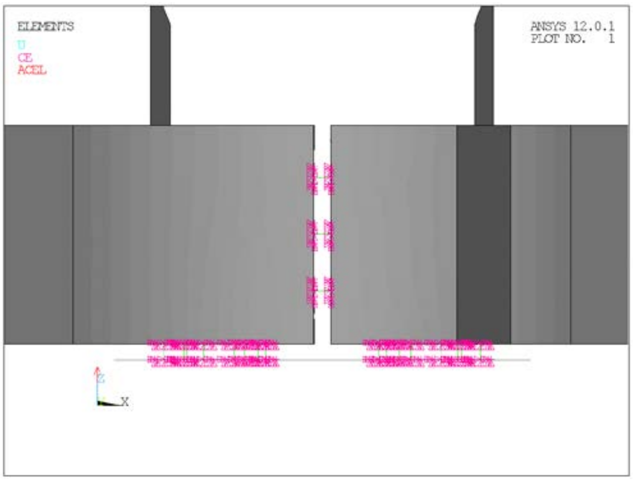


FIG. 10 PROFILE VIEW OF THE BOP LIFTING FRAME (ZOOMED VIEW)

Boundary Conditions, Loads and Allowable Criteria

Boundary Conditions

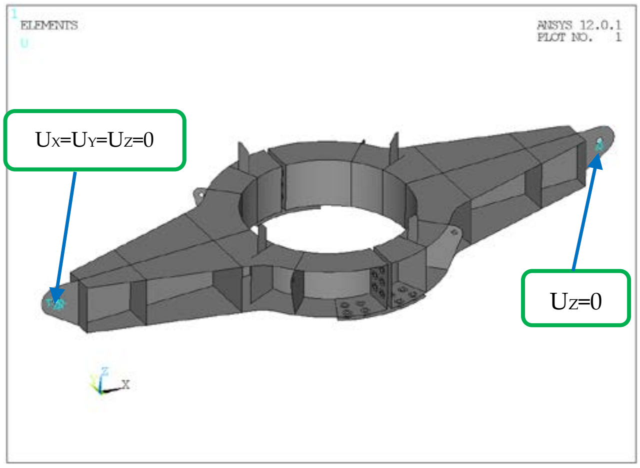


FIG. 11 BOUNDARY CONDITION PLOT OF LIFTING FRAME

Boundary condition, an application of force and constraint is generally given to the model to get real time behavior of the structure while lifting. Lifting frame padeyes are constrained in vertical direction (lift direction) to numerically simulate the lifting frame structure for the design working load. One lifting frame padeye is constrained in all three translations to avoid rigid body motion in Ansys 12.0.1 software, while doing finite element analysis. Boundary condition plot is shown in Fig. 11.

Loads Considered for the FE Analysis

Safe working load of the BOP stack is 34.6 MT (76.27 kips). The Safe working load (SWL) denotes the maximum weight for which lifting frame is certified by classification society to raise, lower or suspend. Safe working load of the BOP stack includes the weight of all ram BOPs and annular BOPs in the stack. Offshore lifting is exposed to significant dynamic effects while lifting the BOP stack that shall be taken into account by applying an appropriate dynamic amplification factor, resulting in DAF being 1.30 for this module.

Design working load of the BOP stack = DAF × SWL

Design working load of the BOP stack is 1.3 × 34.6 = 45 MT (99.21 kips).

99.21 kips load is distributed among the circumferential nodes, 2" away from inner ring edge of the lifting frame. Total number of nodes on circumference of the lifting frame is 94. Load application plot is shown in Fig. 12. Along with the 99.21 kips design working load and pretension load in bolts, self weight of the lifting frame is also considered for the strength assessment of BOP lifting frame.

Load on each node = design working load/total number of nodes = 99.21 / 94 = 1.06 kips.

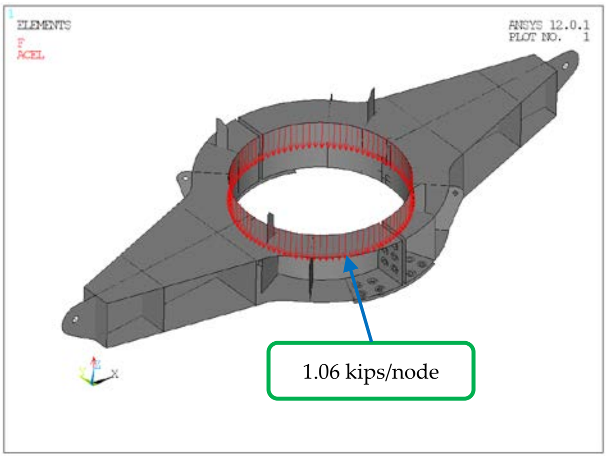


FIG. 12 LOAD APPLICATION PLOT OF THE BOP LIFTING FRAME

Allowable Criteria

Lifting frame will act as a simply supported beam while lifting the BOP stack, reference to Fig. 11 and Fig. 12. Distance between lifting frame padeyes (L) is 147".

Allowable deflection for simply supported beam is 'L/240'.

So allowable deflection for lifting frame is 0.61 in. Allowable von-Mises stress for the lifting frame (static analysis) is $0.56 \times f_y = 0.56 \times 34 = 19.04$ ksi.

Finite Element Analysis Results and Discussions

The finite element analysis is carried out for the BOP lifting frame. Static analysis is performed for the design working load along with self weight of the lifting frame structure. SPARSE matrix solver is used to simulate the lifting frame in Ansys 12.0.1. Options used for contact analysis are given in Table 2. Maximum deflection observed in the lifting frame is 0.008", which is well below the allowable deflection. Deformation plots are shown in Fig. 13 and Fig. 14. The maximum von-Mises stress on lifting frame is found to be 12.323 ksi, less than the allowable stress. Hence structure is safe in strength point of view. Von-Mises stress plots are shown in Fig. 15 to Fig. 17. From the finite element analysis results it is observed that maximum von-Mises stress is found near to the bolt locations, and these high concentrated stresses are due to the rigid connections. The von-Mises stress distribution on the lifting frame parts is not similar because of the difference in locations of the annular guides and its support structure.

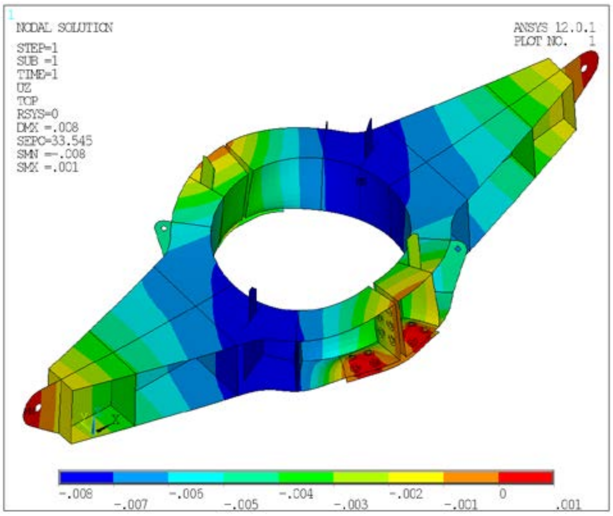


FIG. 13 VERTICAL DEFORMATION PLOT OF BOP LIFTING FRAME (INCHES) (DISPLACEMENT SCALE IS 1:300)

TABLE 2 OPTIONS USED FOR THE CONTACT ANALYSIS IN ANSYS 12.0.1

Behavior of the contact surface	Standard
coefficient of friction	0.02
contact algorithm	Augmented Lagrange Method
stiffness matrix	Symmetric
Initial penetration	include everything
Automatic contact adjustment	Close gap/reduce penetration
Element time increment	Maintain reasonable

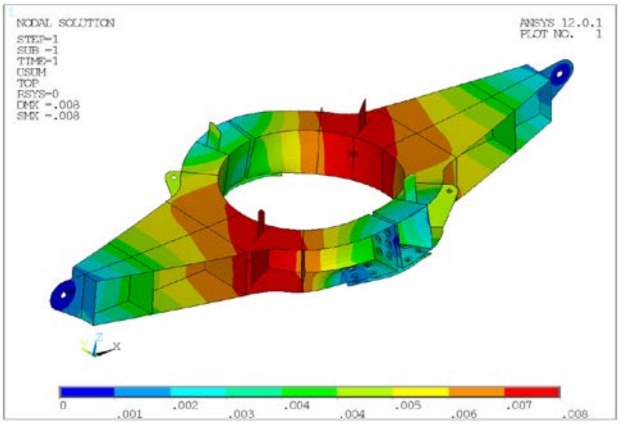


FIG. 14 TOTAL DEFORMATION PLOT OF BOP LIFTING FRAME (INCHES) (DISPLACEMENT SCALE IS 1:300)

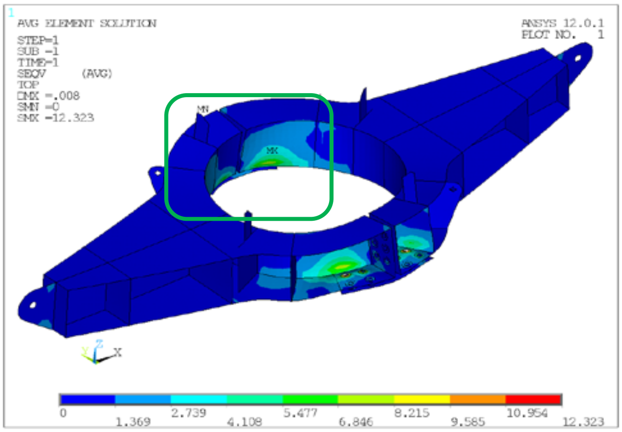


FIG. 15 VON-MISES STRESS PLOT OF BOP LIFTING FRAME, MAXIMUM STRESS IS 12.32 KSI

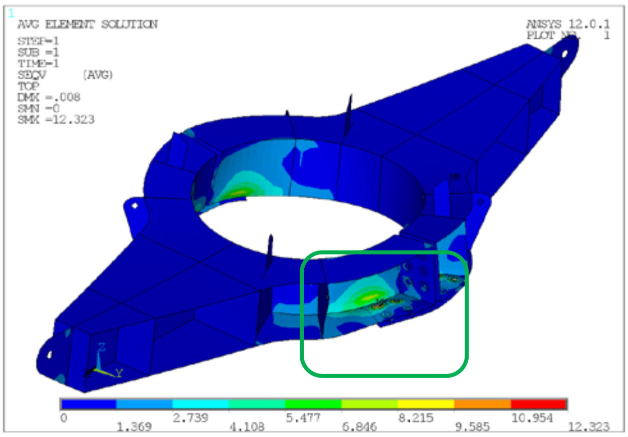


FIG. 16 VON-MISES STRESS PLOT OF BOP LIFTING FRAME, MAXIMUM STRESS IS 12.32 KSI

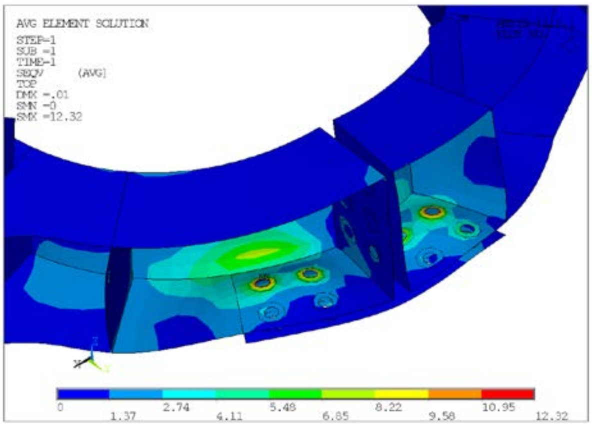


FIG. 17 VON-MISES STRESS PLOT OF BOP LIFTING FRAME (KSI), ZOOMED VIEW

Design of Lifting Frame Padeye

Lifting frame pad eye is designed for total load of 103.5 kips. Design working load of the BOP stack is 99.21 kips (45 MT) and self weight of the lifting frame is 4.29 kips (1.95 MT). Total reaction force at each lifting padeye is 51.75 kips, and reaction force of 49.605 kips on each lifting padeye is due to the design working load of BOP stack. Cheek plate of thickness 0.5" is given to the lifting padeye at either side of the padeye holes to resist against the loads. Lifting padeye is designed for bending stress, shear stress and bearing stress. Material properties of the lifting frame and lifting frame padeyes are similar.

Detailed calculations and the lifting pad eye are shown in below and Fig. 18.

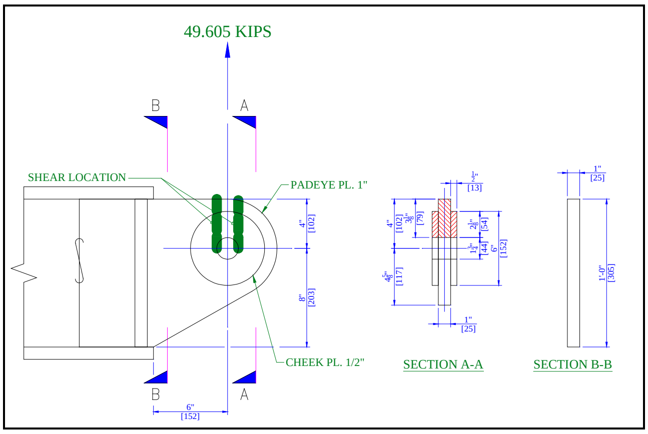


FIG. 18 DETAILS OF LIFTING FRAME PADEYE

Lifting Frame Padeye Design for Bending Stress

Lifting padeye will tend to bend about section B - B while lifting the BOP stack, reference to Fig. 18. Reaction force on each lifting padeye is 51.75 kips. Lifting padeye thickness is 1".

Moment of inertia about major axis of the section B – B

$= 1 \times 12^3/12 = 144$ in^4

Neutral axis distance is half of the depth of section B - B, 12/2 = 6"

Section modulus = moment of inertia / neutral axis distance = 144 / 6 = 24 in^3

Distance from padeye hole center to section B – B is 6"

Bending moment about section B – B = 51.75 × 6" = 310.5 kip-in

So bending stress as per bending equation is equal to Bending moment/Section modulus = 310.5 / 24 = 12.93 ksi

Allowable bending stress is $0.6 \times f_y = 0.6 \times 34 = 20.4$ ksi

Actual bending stress in the lifting padeye is less than the allowable bending stress so lifting padeye is 'safe' in bending stress point of view.

Lifting Frame Padeye Design for Shear Stress

Reaction force on each lifting padeye is 51.75 kips, in lift direction. Padeye will shear in two areas in lift direction (Z-direction). Dimensions and shear locations are shown in Fig. 18. Distance from pin hole edge to outer edge of the lifting frame in lift direction is 3.125". Distance from pin hole edge to outer edge of the cheek plate is 2.125" and cheek plate thickness is 0.5".

Double shear area, reference to section A - A = 2 × (1" × 3.125" + 2 × 0.5" × 2.125") = 10.5 in^2

So shear stress on lifting padeye is Force / Shear area = 51.75 / 10.5 = 4.93 ksi

Allowable shear stress is $0.4 \times f_y = 0.4 \times 34 = 13.6$ ksi

Actual shear stress in the lifting padeye is less than the allowable shear stress so lifting padeye is 'SAFE' in shear stress point of view.

Lifting Frame Padeye Design for Bearing Stress

Reaction force on each lifting padeye is 51.75 kips

Pin hole diameter of the padeye is 1.75" (44 mm); while Pin diameter is 1.61" (41 mm)

Lifting padeye thickness is 1"; and Cheek plate thickness is 0.5"

Thickness of the lifting pad eye for bearing is 2" (1" + 2 × 0.5")

Bearing area = pin diameter × thickness of the padeye

= 1.61" × 2" = 3.22 in^2

So bearing stress on lifting padeye = Load/Bearing area

= 51.75/3.22 = 16.07 ksi

Allowable bearing stress is 0.75× f_y = 0.75×34 = 25.5 ksi

Actual bearing stress in the lifting padeye is less than the allowable bearing stress so lifting frame padeye is 'safe' in bearing stress point of view. Hence lifting frame padeye is safe in strength point of view for the applied loads.

Design Calculations of Hexagonal bolt 1 1 /8" φ × 4" LG (ASTM A 325 Grade)

Bolts take major part of the load while lifting the BOP stack. Vertical face plate bolts are in tension and shear during the lifting operation where as bottom connecting plate bolts are under shear. So the vertical plate bolts are designed for both shear and tension capacity. Bottom connecting plate bolts are designed for shear and for bearing strength at bolt holes. Number of bolts on each vertical face plate is 6. Eight number of bolts are used to connect bottom connecting plate with bottom plate of the lifting frame on each side. So the total number of bolts used for the design of BOP lifting frame design is 28 (2 × 6 + 2 × 8). Bolt size is hexagonal 1 1 /8" φ × 4" LG bolt (ASTM A 325 Grade). Lifting frame acts as a simply supported beam during the lifting operation. So the maximum bending moment will occur at the mid part of the lifting frame. This moment will be equally distributed between the two vertical face plates joints. Refer to Fig. 19 for details.

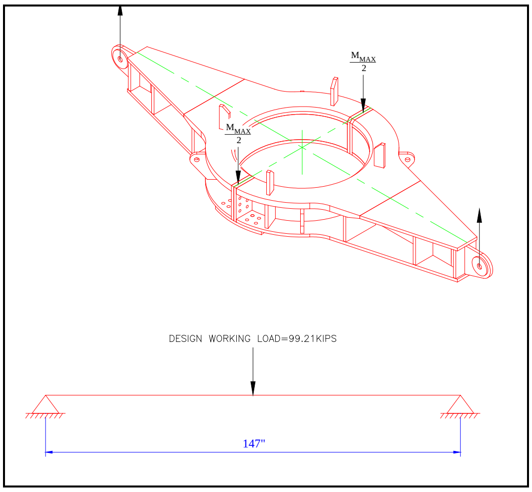


FIG. 19 MAXIMUM BENDING MOMENT CALCULATIONS PLOT

The formula for maximum bending moment for simply supported beam with point load at midpoint is WL / 4.

Maximum bending moment, WL / 4 = 99.21 × 147" / 4 = 3646 kip-in

Maximum bending moment at joining locations is 3646/2 = 1823 kip-in. Refer to Fig. 19.

Design of Bottom Bolts for Shear Force

Bottom connecting plate bolts are oriented along the depth of the lifting frame. Forces at bottom bolt locations are calculated by using maximum induced bending moment in the lifting frame. Details of the vertical face plate bolts are given in Fig. 20.

Maximum bending moment at each vertical face plates joint is 1823 kip-in

Distance from top of the vertical face plate to bottom connecting plate is 14".

Sum of the square distances is $3.625^2 + 7^2 + 10.375^2 + 14^2 = 365.75\ in^2$

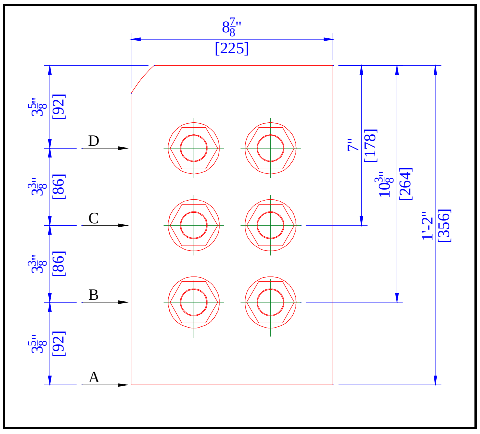


FIG. 20 DETAILS OF VERTICAL FACE PLATE BOLTS

Shear force on bottom bolts (at A, refer Fig. 20) is equal to (maximum bending moment × distance)/sum of the square distances that is, 1823 × 14 / 365.75 = 69.77 kips.

Allowable shear capacity for each 1 1/8" bolt is 16.9 kips

Allowable shear capacity for 4 bolts (4 bolts are located on each part per each side) is 4 × 16.9 = 67.6 kips

Unit check ratio is Shear force at bottom bolts / shear capacity of bolts, that is, 69.77 / 67.6 = 1.03.

Unit check ratio is slightly higher than 1, which is acceptable because of the conservative design working load is considered for the design. Bottom bolts are safe in shear point of view.

Design of Vertical Face Plate Bolts for Shear Force

Vertical face plate bolts are oriented along the length of the lifting frame. The maximum reaction force at

each lifting frame padeye is 49.605 kips due to the design working load of 99.21 kips (45 MT). This reaction force is reason for the shear stress in horizontal bolts.

Shear force on each vertical face plate is 49.60/2, that is 24.8 kips.

There are total 6 bolts on each vertical face plate, bolts cross sectional area being 0.994 in^2

Shear stress in each bolt, f_υ is total shear force/ (no. of bolts × bolt cross sectional area),

that is equal to 24.9/(0.994 × 6) = 4.18 ksi

Allowable shear stress for each 1 1/8" bolt is 17 ksi

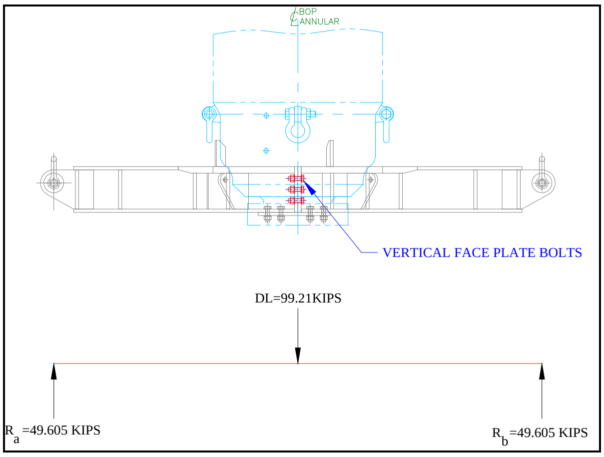


FIG. 21 SHEAR FORCE CALCULATION PLOT AT EACH VERTICAL FACE PLATE

Actual shear stress in horizontal bolts is less than the allowable shear stress, so horizontal bolts are 'safe' in shear force point of view.

Design of Vertical Face Plate Bolts Against Combined Both Shear Force and Tension Force

Shear stress in horizontal bolts, f_υ is 4.18 ksi

Bolts cross sectional area is 0.994 in^2

Maximum bending moment at joining locations is 3646/2 = 1823 kip-in. Refer to Fig. 19.

Tension force in the horizontal bolts is calculated by using maximum induced bending moment in the lifting frame.

Tension load at 'B' (Maximum tension will occur in third row of bolts which are at 10 3/8" from top of the vertical plate, refer Fig. 20 for details) is (maximum bending moment × distance)/sum of the square distances

= 1823 × 10.375" / 365.38

= 51.71 kips on two bolts

Tension load on each horizontal bolt is 51.71 / 2, that is 25.86 kips

Allowable tension stress combined with shear stress in the horizontal bolts is $\sqrt{(44^2 - 4.39 \times f_v^2)}$

that is, $\sqrt{(44^2 - 4.39 \times 4.18^2)}$ = 43.12 ksi

Allowable tension load on nominal area is tension stress × cross sectional area (43.12 × 0.994) = 42.86 kips

Allowable tension load on tension area is tension stress × cross sectional area (excluding threaded area), that is, 43.12 × 0.763 = 32.9 kips.

Actual tension load combined with shear force in horizontal bolts is less than the allowable tension load, so horizontal bolts are 'safe' for combined tension and shear loads.

Design Against Bearing Strength at Bolt Holes Through Horizontal Bottom Connecting Plate

Horizontal bottom plate thickness is 1",

Minimum edge distance from the bolt center is 2",

Diameter of bolt is 1 1/8 ",

Bearing load at bottom bolts (at A, reference to Fig. 20) is (maximum bending moment × distance) / sum of the square distances, that is, 1823 × 14 / 365.75 = 69.77 kips

Horizontal bearing load (4 bolts are located on each part per each side) at each bolt is 69.77/4 = 17.44 kips

Allowable bearing load at bolt holes for 2" edge distance is 48.9 kips.

Actual bearing load near horizontal bolts is less than the allowable bearing load, so bottom connecting bolts are 'safe' for bearing point of view. Hence hexagonal 1 1 /8" φ × 4" LG bolts are safe in strength point of view for the applied loads.

Annular Locking Padeye Design

Annular locking padeye is designed for bending stress, shear stress and bearing stress. Material properties of the lifting frame, annular locking padeyes and annular guides are similar. Detailed calculations are given below; while details of the annular locking pad eye are shown in Fig. 22. 9.5 MT SWL shackles are used to tie the annular locking padeyes with annular lugs. Design working load of the shackle is 1.3 × safe working load

that is, 1.3 × 9.5 = 12.35 MT (27.22 kips)

Annular Locking Padeye Design for Bending Stress

Annular locking padeye will tend to bend about

section C – C, while lifting the BOP stack.

Design load on each locking padeye is 31.41 kips

Distance from annular locking padeye pin hole center to the section C – C is 2.125"

Moment of inertia about major axis of the section C – C is 1 × 11^3 / 12, that is 110.92 in^4

Neutral axis distance is half of the depth of the section, is 5.5" (Reference to Fig. 19, section C - C).

Section modulus is moment of inertia/neutral axis distance, that is, 110.92 / 5.5 = 20.17 in^3

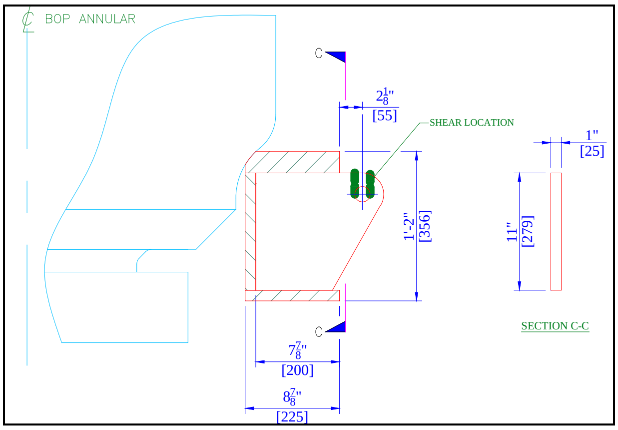


FIG. 22 DETAILS OF ANNULAR LOCKING PADEYE

Moment about section C – C (27.22 ×2.125") is 57.84 kip-in

So bending stress as per the bending equation is Bending moment/Section modulus

= 57.84 / 20.17 = 2.87 ksi

Allowable bending stress is 0.6 × f_y, that is, 0.6 × 34 = 20.4 ksi

Actual bending stress in the annular locking padeye is less than the allowable bending stress, so annular locking padeye is 'safe' in bending stress point of view.

Annular Locking Padeye Design for Shear Stress

The designed working load on each annular locking padeye is 27.22 kips. Padeye will shear in two areas along the pull direction near pin hole, and approximate shear locations are shown in Fig. 22. Distance from pin hole center to outer edge of the locking padeye in lift direction is 2". Diameter of the annular locking padeye pin hole is 1 7/16" (lift direction). Annular locking padeye thickness is 1".

Double shear area is 2 × [(2" – 0.719") × 1"] = 2.56 in^2

Shear stress in locking padeye is Force/Shear area, that is, 27.22 / 2.56 = 10.63 ksi

Allowable shear stress is 0.4 × f_y, that is 13.6 ksi

Actual shear stress in the annular locking padeye is less than the allowable shear stress, so annular locking padeye is 'SAFE' in shear stress point of view.

Annular Locking Padeye Design Against Bearing Stress

Design working load on each locking padeye is 31.41 kips

Pin hole diameter of the padeye = 1 7/16" (37 mm)

Pin diameter = 1.25" (32 mm)

Thickness of the pad eye (for bearing) = 1"

Bearing area = pin diameter × thickness of the padeye

= 1.25" × 1" = 1.25 in^2

So bearing stress on locking padeye is Load / Bearing area, that is, 27.22 / 1.25 = 21.78 ksi

Allowable bearing stress is 0.75 × f_y, that is 0.75 × 34 = 25.5 ksi

Actual bearing stress in the annular locking padeye is less than the allowable bearing stress, so annular locking padeye is 'safe' in bearing stress point of view. Hence annular locking padeye is safe in strength point of view for the applied loads.

Conclusions

Lifting frame is designed for design working load of the BOP stack along with self weight of the lifting frame structure. As expected lifting frame is deflected more at middle part of the lifting frame. The maximum deflection obtained in the lifting frame structure is less than the allowable deflection limit. Bottom connecting plate and inner ring structure of the lifting frame experience more stresses than the remaining part of the lifting frame. The maximum von-Mises stress in the lifting frame structure is well below the allowable stress limit. Hexagonal 1 1 /8" φ × 4" LG bolt is safe for the applied design working load. Lifting padeyes and annular locking padeyes strength are also checked with the applied design working load and found to be safe. Hence, the BOP lifting frame is safe in strength point of view for the applied loads.

Nomenclature

W Design working load;

L Length between the lifting frame padeye bolt centers;

U_X Translation in X - direction;

U_Y Translation in Y - direction;

U_Z Translation in Z - direction;

M_{max} Maximum bending moment of the lifting frame;

MT Metric tonne;

f_y Yield strength of the material;

f_u Ultimate tensile strength of the material;

Ksi Kips per square inch.

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